SOIL MOISTURE CHARACTERIZATION USING MULTI-ANGULAR POLARIMETRIC RADARSAT-2 DATASETS

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ABSTRACT

The use of multi-angular polarimetric datasets instead of the standard single-angular data is considered to be a solution to improve the effectiveness of bare soil characterization. However, the potential of polarimetric parameters derived from the multi-angular SAR datasets was studied little, particularly for the C band polarimetric datasets. In this study, the sensitivity of polarimetric descriptors from single and multiple incidence angle acquisitions is investigated against in situ soil moisture and surface roughness. The behaviours of polarimetric descriptors are compared with the simulations using integral equation model (IEM). The results show that the variation of polarimetric descriptors in term of soil moisture as well as surface roughness is in accordance with the IEM simulations; even though the variation scale is different between the real data and simulation (The simulation is more sensitive than the real data). The polarimetric sensitivity found in this study provides additional evidences for the potential utilization of multi-angular polarimetric SAR datasets for bare surface characterization.

1. INTRODUCTION

Soil moisture is an essential parameter for the study of hydrology, meteorology, and particularly agricultural cultivation. The studies on characterization and retrieval of this parameter using polarimetric SAR data have been carried out extensively in [1] [2]. The SAR signature is affected by not only soil moisture, but also the surface roughness, which determines the scattering type. In addition, the backscattering signature is dependent on incidence angle, polarization and frequency [3]. The multi-angular, multi-polarization and multi-frequency SAR datasets provide more observing dimension, which has potential to improve the ground information extraction ability [4].

The possibility to apply multi-angular datasets for robustness improvement in surface parameter retrieval was demonstrated in the most common semi-empirical approach [1]. The advantages of multi-angular and multi-polarization approaches were compared in [5], indicating multi-angular configuration provides more dynamic to bare soil status than multi-polarization. Two images acquired at low incidence angle and high incidence angle are proposed to separate the roughness effect, and to relate the backscattering coefficients only with soil moisture [6]. An original surface roughness descriptor was proposed in [7] to combine the horizontal and vertical statistical roughness profile, and this roughness descriptor is retrieved directly from the difference between two incidence angle data. An additional image acquired under quite dry condition was suggested to improve the approach [7] in order to solve the horizontal and vertical roughness separately [8]. By examining the different incidence angle datasets, it is demonstrated that large incidence angle image is more suitable to retrieve surface roughness, while small incidence angle image is more appropriate to invert soil moisture [9].

The polarimetric parameters for surface roughness and soil moisture characterization are studied little, especially in C band and using multi-angular configuration. The X-Bragg model was reported in [10] based on the Eigen decomposition methodology [4], in which the soil moisture is derived from Entropy/Alpha space, while surface roughness is derived directly from Anisotropy. However, this approach is not applicable in C band due to the limited roughness range requirements. Based on the application of multi-frequency datasets, [11] proposed a soil parameter retrieval approach, combining the IEM model [3] and polarimetric Eigen decomposition [4], assuming the reflection symmetry is satisfied for natural environment. The soil moisture is estimated directly from first scattering mechanism indicator $SR\alpha1$, which is reported to depend more on soil moisture than roughness at high frequency as C/X band.

The objective of this study is to investigate the sensitivity of linear HH polarised signature and polarimetric descriptor $SR\alpha1$ in term of soil moisture and surface roughness. Except for the individual angle comparison, the sensitivity of two angular observation differences (ΔHH and $\Delta SR\alpha1$) is meanwhile examined as a function of soil variables. Three multi-angular RADARSAT-2 images along with the simultaneous ground truth measurements are presented in section 2. The polarimetric sensitivity analysis and comparison with IEM simulation are conducted in section 3. The dataset behaviours are concluded in section 4.

2. EXPERIMENTAL DATASETS

The study agricultural fields are located in the site of Pleine-Fougères, near the Mont-St-Michel (N °48′31′, E 1°15′) in France. Most of land is covered by corn, wheat while some of land is left as bare, which is the interesting plots in this study. The loamy soil is dominant in the soil composition. The selected bare fields are flat but some of them are with ridge due to the tillage operation. The anisotropic parcels with ridge are excluded, and merely the isotropic parcels are analyzed in this work.

Multi-angular single look complex (SLC) fully polarimetric RADARSAT-2 images are acquired in ascending (24° image on 23/04/2013 and 49° image on 05/04/2013) and descending orbit (31°image on 23/04/2013) (in Fig.1) over test site. The raw data are extracted as coherence matrix T3, and a 7×7 boxcar filter is applied using PolSARpro4.2. The polarimetric images are Ortho-rectified and co-registered using NEST. The common region (shown in Fig.1 as Paul representation) of individual multi-angular images is extracted for further study. All the selected test fields are located in the common region. The incidence angle effect is demonstrated in Fig.2 that the single bounce decreases as incidence increases from 24° to 49° .

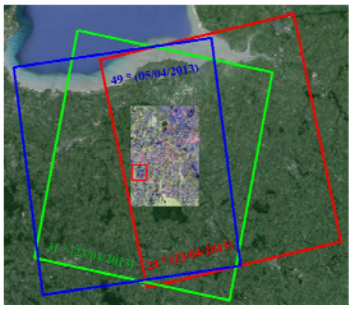
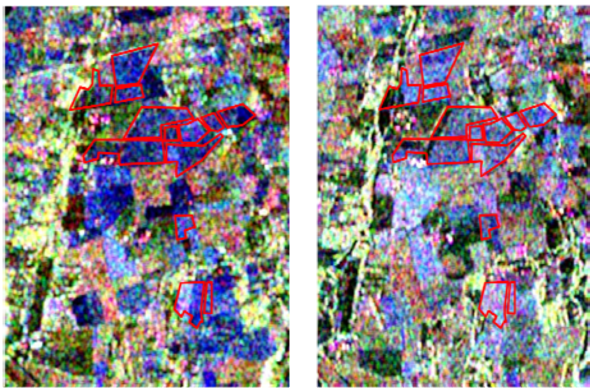


Figure 1. Multi-angular RADARSAT-2 swaths



(a) (b)

Figure 2. Pauli image: single bounce variation in term of incidence angle changed from (a) 24° to (b) 49° .

Ground truth measurements of surface roughness and soil moisture were carried out along with the SAR acquisitions over bare parcels (Some of the parcels are shown in Fig.2). Soil moisture from top 3.8cm is measured using a calibrated Time Domain Reflectometry (TDR) 20 times for each parcel. The soil moisture ranges from 8% to 30% over test sites in April. Soil roughness is measured by a simpler and faster chain approach proposed by Saleh [12], which is based on the principle that as a chain of given length is placed across a surface, the covered horizontal distance decreases as surface roughness increases. Therefore, the Saleh Roughness Factor (SRF) is defined as

$$\mathrm{SRF} = 100(1-\frac{L2}{L1}) \qquad (1)$$

Where *L1* is the length of given chain (146.5cm in this case), *L2* is the chain covered horizontal distance. Thus, as surface roughness increases, L2 decreases, resulting in the increases of SRF. Considering the surface roughness is normally characterized as Random Roughness Factor (root mean square height of surface profile *s*) obtained using laser/pin roughness meter, a transformation relationship in Eq.2 is derived based on simultaneous measurements using both laser and chain approach.

$$s(\mathrm{cm})=0.50715\mathrm{SRF}^{0.7867} \qquad (2)$$

The SRF is measured 10 times for each parcel in two perpendicular directions. The *in situ* surface roughness and soil moisture over each parcel is assumed to be the average value of repeated measurements.

The meteorological data in Fig.3 were obtained from the nearest meteorological observing station, including the hourly temperate and hourly rainfall amount. The rainfall amount on 05/04/2013 when 49° image was acquired and corresponding *in situ* data were collected was 8.2mm, which causes the soil moisture increase. In contrary, no rainfall is observed from 28/04/2013 to 23/04/2013, which is reasonable to assume the soil moisture and surface roughness are quasi-invariant during the acquisitions of 24° and 31° images and simultaneous campaign (Two images acquired in quasi-invariant soil status are the requirement for multi-angular model).

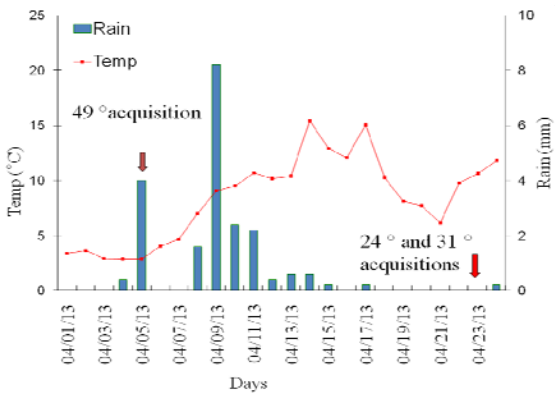


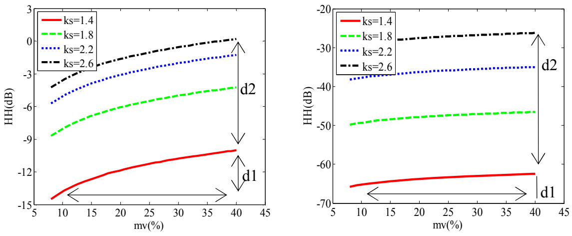
Figure 3. Meteorological records corresponding to the acquisition and campaign at station close to test sites.

3. POLARIMETRIC ANALYSIS

The sensitivity of linear polarization signature and polarimetric parameter to soil moisture *mv* and surface roughness *ks* (*k* is the wave number) is analyzed in this section. The behaviours of RADARSAT-2 datasets are compared with the simulation using IEM (selecting Gaussian correlation function and set autocorrelation length as kl=15), neglecting the scale difference between real data and model.

3.1. HH polarization signature

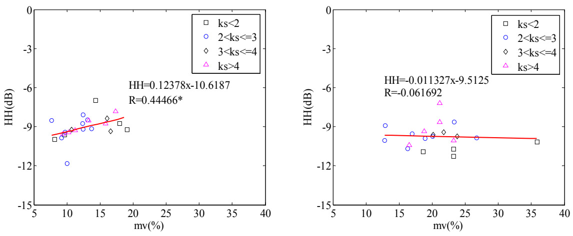
The sensitivity of HH linear polarization signature against soil moisture for different roughness status is simulated in Fig.4 using a low incidence angle 24° and a high incidence angle 49°. It is visible that as ks increases, the roughness contribution to the total backscattering coefficient decreases, particularly for small incidence angle data. The ratio of soil moisture effect (d1) and roughness effect (d2) is 0.37 at small incidence angle and 0.076 at large incidence angles, which indicates that at higher incidence angle, the HH signature is predominated by surface roughness.



(a) (b)

Figure 4. Behaviour of HH using IEM in term of mv and ks for incidence angle (a) 24°; (b) 49°.

The sensitivity of HH derived from RADARSAT-2 images in respect of soil moisture and surface roughness is shown in Fig.5, indicating the real HH signature is sensitive to soil moisture at small incidence angle 24° significantly (In Fig.5a, * means statistical significance test result $p < 0.05$). At high incidence angle, no correlation between HH signature and soil moisture is found, but significant roughness effect is observed in Fig.5b, which is in accordance with the behaviour of IEM simulation even though the individual data scale is different.



(a) (b)

Figure 5. Behaviour of HH using RADARSAT-2 data in term of mv and ks for incidence angle (a) 24°; (b) 49° .

3.2. Polarimetric descriptor

At high frequency and for natural environment where the reflection symmetry is satisfied, the $SR\alpha 1$ from first eigenvector is limited as Eq.3 in [13]

$$SR\alpha_1 = \arctan \left(\frac{2 f_{hh} f_{vv}^* - (| f_{vv} |^2 - | f_{hh} |^2 + \sqrt{(| f_{vv} |^2 - | f_{hh} |^2)^2 + 4 | f_{hh} f_{vv}^* |^2})}{2 f_{hh} f_{vv}^* - (| f_{vv} |^2 - | f_{hh} |^2 + \sqrt{(| f_{vv} |^2 - | f_{hh} |^2)^2 + 4 | f_{hh} f_{vv}^* |^2})} \right)$$

Where $f_{hh} = -2\Gamma_{hh} / \cos\theta$ and $f_{vv} = 2\Gamma_{vv} / \cos\theta$ (3)

and Γ is the Fresnel coefficient

The sensitivity of $SR\alpha 1$ as a function of soil moisture and incidence angle is demonstrated in Fig.6, indicating $SR\alpha 1$ decreases with soil moisture increases. And it is obvious that at high incidence angle, $SR\alpha 1$ is more sensitive to soil moisture than at low incidence angle.

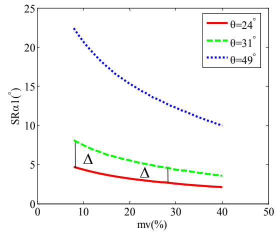
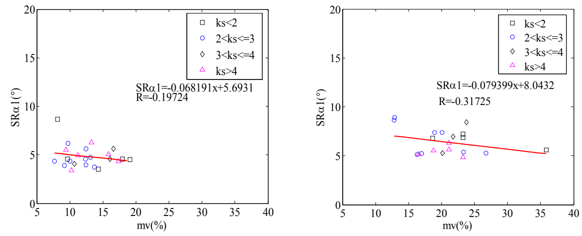


Figure 6. Behaviour of SRα1 using IEM in term of mv and ks for three incidence angles.



(a) (b)

Figure 7. Behaviour of SRα1 using RADARSAT-2 data in term of mv for incidence angle (a) 24°; (b) 49° .

The $SR\alpha 1$ in Fig.7 decreases with soil moisture for both low and high incidence angle data, but the sensitivity to soil moisture is obviously improved at high incidence angle, which is in agreement with the IEM simulation. Since the RADARSAT-2 datasets presented in Fig.2 as Pauli RGB show that the single bounce decreases when incidence angle becomes large, thus the behaviour of $SR\alpha 1$ at high incidence angle provides an alternative potential for soil moisture characterization by just using high incidence angle polarimetric data.

3.3. Two angular difference Δ descriptor

The behaviour of ΔHH is quasi independent on soil moisture as shown in Fig.8, verifying the possibility to use two incidence angle observing difference to separate the surface roughness contribution in order to estimate soil moisture accurately. The ΔHH derived from two RADARSAT-2 images is shown in Fig.9a, demonstrating that ΔHH is significantly relative to surface roughness regardless the soil moisture. It should be noted that in Fig.9b, it is also statistically fitted that ΔSRα1 is inversely relative with soil moisture, even though the correlation is quite weak (R=-0.1448), in accordance with the variation trend of simulated Δ SRα1 shown in Fig.6.

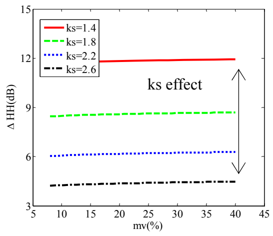
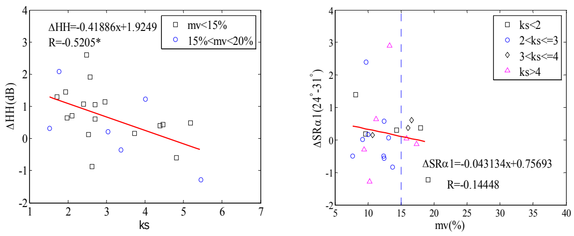


Figure 8. Behaviour of ΔHH using IEM in term of mv and ks for incidence angles 24° vs 31°.



(a) (b)

*Figure 9. Behaviour of (a)ΔHH, (b) Δ*SRα1 *using RADARSAT-2 data in term of ks and mv two incidence angle 24° vs 49°.*

4. CONCLUSION

With the aim to study the potential use of C-band multi-angular polarimetric datasets for bare agricultural characterization and further parameter retrieval, the linear signature HH and a polarimetric parameter *SRα1* are extracted from RADARSAT-2 datasets and compared with the behaviours of IEM simulation. The study verifies that HH at low incidence angle is more relative to soil moisture while HH at high incidence angle is more dependent on surface roughness. The polarimetric parameter *SRα1* is noticed to decreases with soil moisture and the sensitivity is improved at high incidence angle. Multi-angular descriptor Δ HH is found to decrease with surface roughness while no relation is observed with soil moisture, in accordance with IEM simulation and the results obtained by [7]. In addition, ΔSRα1 is weakly relative with soil moisture but the variation trend is in agreement with simulation. The dynamic scale of polarimetric descriptors derived from RADARSAT-2 dataset is less than the corresponding descriptors simulated from IEM model, even though the variation trends in term of soil moisture and surface roughness are in accordance. Thus, the IEM model is required to be adapted for modelling the RADARSAT-2 data behaviours with the same scale.

5. REFERENCES

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